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# DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150705

## SOLAR HEATING AND COOLING SYSTEM DESIGN AND DEVELOPMENT (A Quarterly Summary)

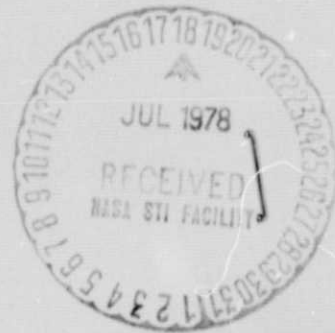
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Under Contract NAS8-32092 with

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George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy



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## Solar Energy

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## FOREWORD

This document summarizes the status of Contract NAS8-32032 for Solar Heating and Cooling Subsystem Development. The contract was initiated on 1 July 1976. The program scope is to develop, fabricate, install and monitor the operation of prototype solar heating and solar heating and cooling systems. Application studies have been completed for three application categories: (1) Single Family Residential, (2) Multi-family Residential and (3) Commercial.

The program currently consists of development of heating and cooling equipment for single-family residential and commercial applications and eight operational test sites (four heating and four heating and cooling). Four are single-family residences and four are commercial buildings.

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# SECTION I

## INTRODUCTION

This project, a part of the Marshall Space Flight Center program for the development of solar heating and combined solar heating and cooling systems<sup>(1)</sup>, involves the complete design and development of marketable systems for single family and commercial applications and the delivery, installation, and monitoring of the prototype systems. The development of the two types of systems is proceeding in parallel with selected commonality of system elements. The time required for the development of the combined heating and cooling systems is greater than for the heating systems, so the heating systems are being installed while development of the cooling subsystem continues. It is convenient to discuss the systems separately in the sections of this document.

A summary program schedule is shown in Figure 1-1.

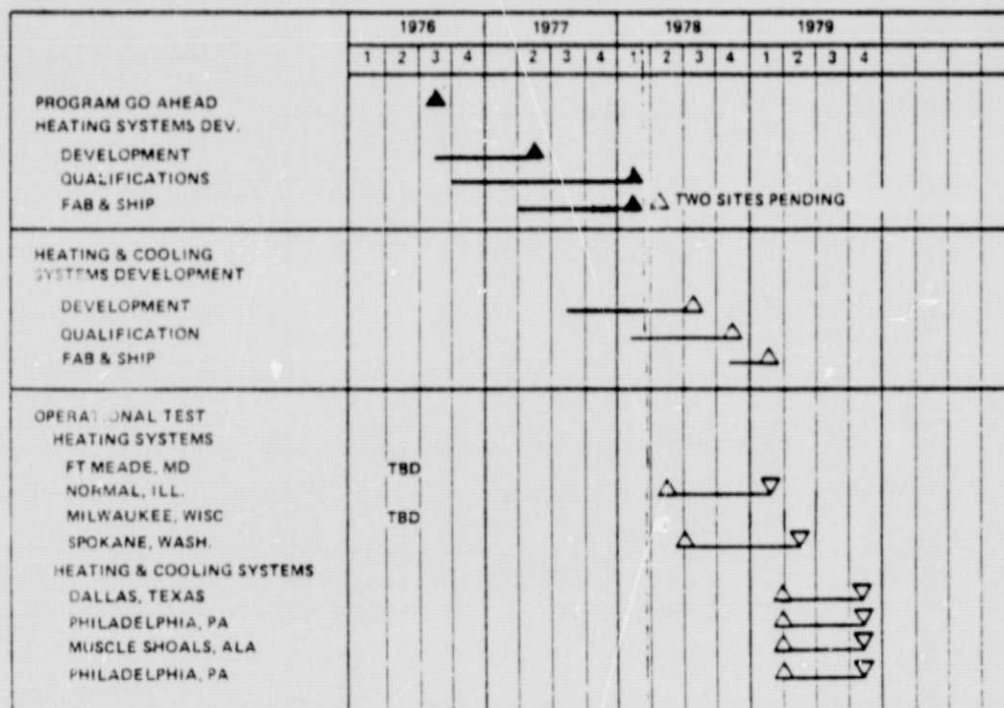


Figure 1-1. Summary Program Schedule

(1) This program is a part of the Department of Energy's activity to develop and demonstrate solar heating and combined heating and cooling systems.



1.1 Program Direction (WBS 1.1.1)

During this period program operation continued in the manner established during the initial quarters. The program team shown in Figure 1.1.1, is the same as shown in the last quarter except for the following change:

1. K. Hanson, Deputy Program Manager assigned to another project.

A Quarterly Review (1/31/78) and a Management Technical Briefing (2/1/78) were held this period in Huntsville.

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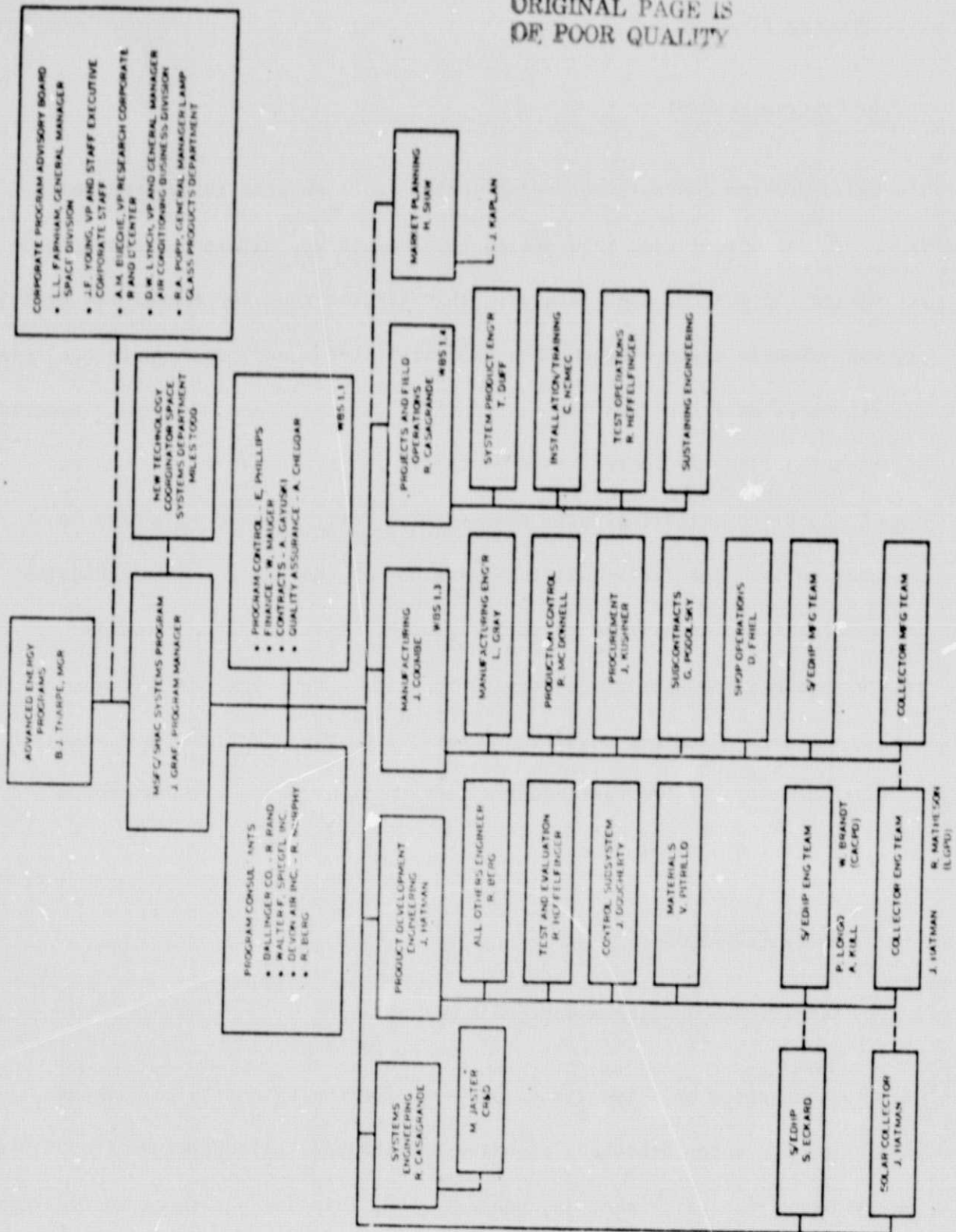


Figure 1-2 Program Organization



## 1.2 Program Planning and Control

### 1.2.1 Program Control

The basic program control tool being used on this program is the control room. It was used during this period to schedule key milestones and program activities and monitor their status. This control room represents the official program schedule against which GE's technical status and progress is monitored. The scheduled data required for the monthly, quarterly and management reports is extracted from the control room posting. The schedules in the control room include the overall program summary with detailed task schedules on the side walls. The individual task sections of the control room schedules are monitored and maintained by the responsible task leaders. Program status meetings are held frequently (3 to 5 times per week) to follow hardware items. Problems involving interactions are identified and resolved at these meetings by the assignment of action items which are posted and monitored in the control room.

## 1.3 Quality Assurance

### 1.3.1 Significant Quality Assurance Activities

With the exception of a few items, hardware for the YWCA site in Spokane, Washington has been inspected, packaged and shipped. Air Force Quality Control has reviewed inspection records, packaging and shipping paperwork and has approved all shipments.

## SECTION 2

### System Development

#### 2.1 Introduction

The major program activity this period was related to the operational test sites and continuation of the design of the S/E DHP. Updates were made to the heating only system schematics to reflect the "as built" configurations. The TC101 collector design proceeded according to plan.

#### 2.2 Analysis and Integration

##### 2.2.1 Baseline Configuration

The heating only system schematic drawings have been updated for the residential and commercial systems. The changes are minor and relate to the addition of check valves to prevent thermal siphoning and to correct the lines between the air separator and TKX-1. There have been no functional changes to the systems. The updated system schematics are included in Figures 2-1 and 2-2 (197B2463 and 65GT).

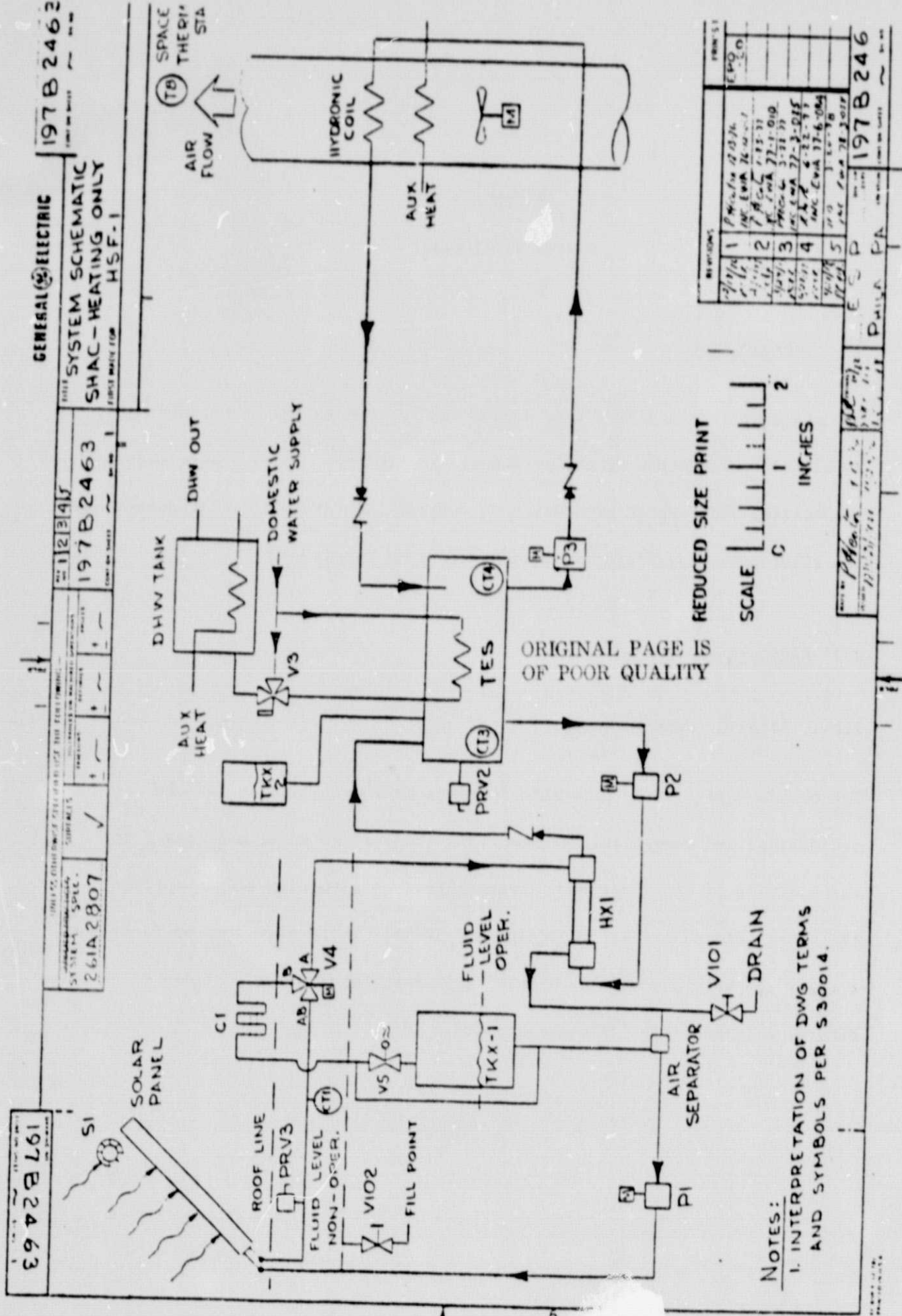


FIGURE 2-1 - SYSTEM SCHEMATIC - HSF

FIGURE 2-2- SYSTEM SCHEMATIC - HCOM

### 2.3 Collectors

GE verification tests were performed and the results correlated well with predicted performance. D.S.T. ASHRAE tests were completed and preliminary indications show the following:

1. Efficiency at low operating temperatures ( $80^{\circ}\text{F}$ ) was slightly higher than anticipated.
2. Efficiency at normal operating temperatures ( $220^{\circ}\text{F}$ ) correlated well with predicted performance.
3. Efficiency at high temperatures ( $300^{\circ}\text{F}$ ) was lower than anticipated.

Presently the DST unit is on a 30 day stagnation test in accordance with HUD requirements which concludes with another performance test. Investigations are being performed to determine the difference between GE and DST results. Areas of investigation include coating degradation, thermal insulation losses, and possible test equipment differences. One collector unit was shipped to Huntsville for indoor solar simulation testing.

Shipping tests on the redesigned frame and serpentine assembly packages were successfully completed. Both the single pack and the multi-pack designs are qualified. It is anticipated that the packing will be redesigned using a less dense material, a thicker section, or both. Palletized shipment of glass is the primary shipping configuration which has not experienced excessive breakage.



Frame corrosion has been the subject of an evaluation caused by the concern of aluminized steel weatherability in the many potential collector environments. The concern is mainly one regarding cosmetics rather than structural integrity of the collector frame. Two additional collector configurations were introduced to provide compatibility for most applications. Options now include:

1. Standard TC-100 configuration, aluminized steel construction.
2. Same as 1 above except exposed edges are treated with a zinc-rich primer for corrosion protection.
3. Completely painted frame for maximum environmental protection.

Impact tests on evacuated glass shroud assemblies were performed using a  $\frac{1}{2}$  inch solid steel sphere dropped from a vertical height of ten feet. The shrouds successfully survived repeated impacts along the length of cylindrical section. The dome/cylinder transition was the weak link where failure occurred at almost each impact at this location. The test was repeated several times using both soda-lime and borosilicate glass of the same geometry (diameter, thickness, length).

The TC-101 collector design is complete. Test modules are in the fabrication cycle with the pacing item being the Alglas reflector. Design and producibility studies of the two-foot fin are complete and performance verification tests show complete compatibility. Clamp-on fin tests have been successful to date.



#### 2.4 Controls

Retrofit of the Solar Integrators at Zia Associates was completed during this period and all units were delivered to Valley Forge. The units have been reworked at Valley Forge to assure reliable field operation. All units will be retested before delivery to the field.

Johnson Controls has delivered the control package for the Heating Commercial installation at Spokane. The package was delivered with all functional controls and indicator lights; however, the System Display Panel which will be mounted on the front of the control package over the indicator lights is still under fabrication by the Panel Department of Johnson Controls. This panel will be added to the package at the field site.

The system controls for both single family and commercial installations are currently under redesign to reflect changes in the Rankine Electric Heat Pump and to incorporate a new three-stage thermostat developed by General Electric Appliance Controls. A request for quotation on the Analog Temperature Switch was released in this time period to prominent HVAC controls, temperature controls and temperature sensor vendors.

#### 2.5 Cooling Subsystems

The following summarizes the cooling subsystem development activities completed during this report period. The cooling subsystems include

3-ton and 10-ton capacity split system solar/electric driven heat pumps and their associated equipment. The emphasis this report period was on the completion of the major component designs and the selection of the 3-ton indoor and outdoor section configurations. Model 1 expander test activities continued in the evaluation of alternate materials, improved performance, and endurance testing.

#### 2.5.1 Subsystem Analysis

Analysis of the design point operating performance for both the 3-ton and 10-ton cooling subsystem was completed.

Analysis was completed in the following areas for the 3-ton outdoor section; component and piping insulation requirements, magnetic drive/clutch losses, fluid transport line sizing, and air horsepower requirements.

A parametric analysis for the Rankine engine vapor generator was completed and subsequently, a procurement specification was prepared for a single vessel vapor generator.

#### 2.5.2 Expander - Model 1

Performance evaluation of alternate materials for end plates and vanes continued during this report period.

$AL_2O_3$  (Metco Pl30SF-10) was identified as a more cost effective ceramic coating as compared to  $Cr_2O_3$  (Union Carbide LC-4). Currently the  $AL_2O_3$  coating is being applied to Model 1 end plates for testing early in the next reporting period.

Process development also continued on Vanasil 77/Ni-Tuff coated vanes. The objective is to obtain a more uniform coating thickness and surface finish.

A 1000 hour endurance test on the Model 1 expander was initiated. On 4/3/78 over 600 hours of operation at design point has been accumulated with no indication of performance degradation. As anticipated, performance improved slightly during the first 100 hours as vanes and other surfaces became better seated. Materials incorporated in the endurance run are as follows:

Stator - Nitrided Nitralloy ( $R_c$  68)

Vanes - Vanasil 77/Ni-Tuff coated

Rotor - 410 Stainless Steel ( $R_c$ -42)

End Plates - Ductile Cast Iron/ $Cr_2O_3$  coated

#### 2.5.2 REH-30/100 Expander

The design and detail drawings for the 3-ton two stage expander has been completed, and fabrication has started. Design of the 10-ton two stage expander has been completed. Preparation and checking of the detail drawings has started and will continue into the next reporting period.

Detailed drawings for both the 3-ton and 10-ton feed pumps has been released, and fabrication is underway.

### 2.5.3 Heat Exchangers

Evaluations of the Rankine vapor generator and regenerator configurations continued through this report period. A compact counter flow (heliflow) vapor generator design and a single-pass counter-flow tube and shell regenerator design are the strongest candidates to date. Final selections will be made early next reporting period.

The rationale for accomplishing liquid preheating, vaporization and superheating of the Rankine engine working fluid in a single vessel is:

1. A single vessel will be more cost effective than several vessels with their associated interconnecting plumbing.
2. A single vessel can be thermally insulated more effectively.  
(The vapor generator inherently is at the highest temperature and must be protected against excessive heat loss.)
3. Rankine fluid inventory will be less for a single vessel configuration.
4. Packaging design is improved with a single vessel.

Several types of heat exchangers were considered for single vessel preheating, vaporization and superheating. However, the most efficient and compact approach was determined to be a counterflow configuration. Calculations indicate the need for 9 tubes approximately 21.3 feet long. A convenient

way for packaging these long tubes is a helical configuration such as the "Heliflow" units produced by the Graham Manufacturing Company.

To maintain the movement of oil, equal distribution of the Rankine working fluid, and to accomplish high heat transfer, the number of tubes and tube diameters have been selected to provide turbulent flow in the liquid phase (pre-heater section) as well as in the two-phase (vaporizer) and vapor phase (superheater section) of the heat exchanger. The Reynolds number for the three sections are:

| <u>Section</u> | <u>N<sub>Re</sub></u> |
|----------------|-----------------------|
| Preheater      | 18,490                |
| Vaporizer      | 22,160 to 227,627     |
| Superheater    | 221,000               |

Figure 2-3 shows the results of the parametric analysis for the 3 ton vapor generator. A design having nine tubes (0.25" O.D. x 0.19" I.D.) in parallel has been tentatively selected. The pressure drop and required I.D. surface area is shown in Figure 2-4. The design point temperature profile as a function of heat transfer is shown on Figure 2-4 along with the tube length for each section of the vapor generator. Although the vapor generator is being designed for a rather low approach temperature of 10°F, the pinch point  $\Delta t$  is a respectable 29°F for the superheat condition shown and for a water side temperature range of 20°F. (Future designs may well take advantage of a higher water side temperature drop.) Tube side  $\Delta P$  will be  $\sim 3.5$  psi and water side  $\Delta P$  will be  $\sim 2.7$  psi.

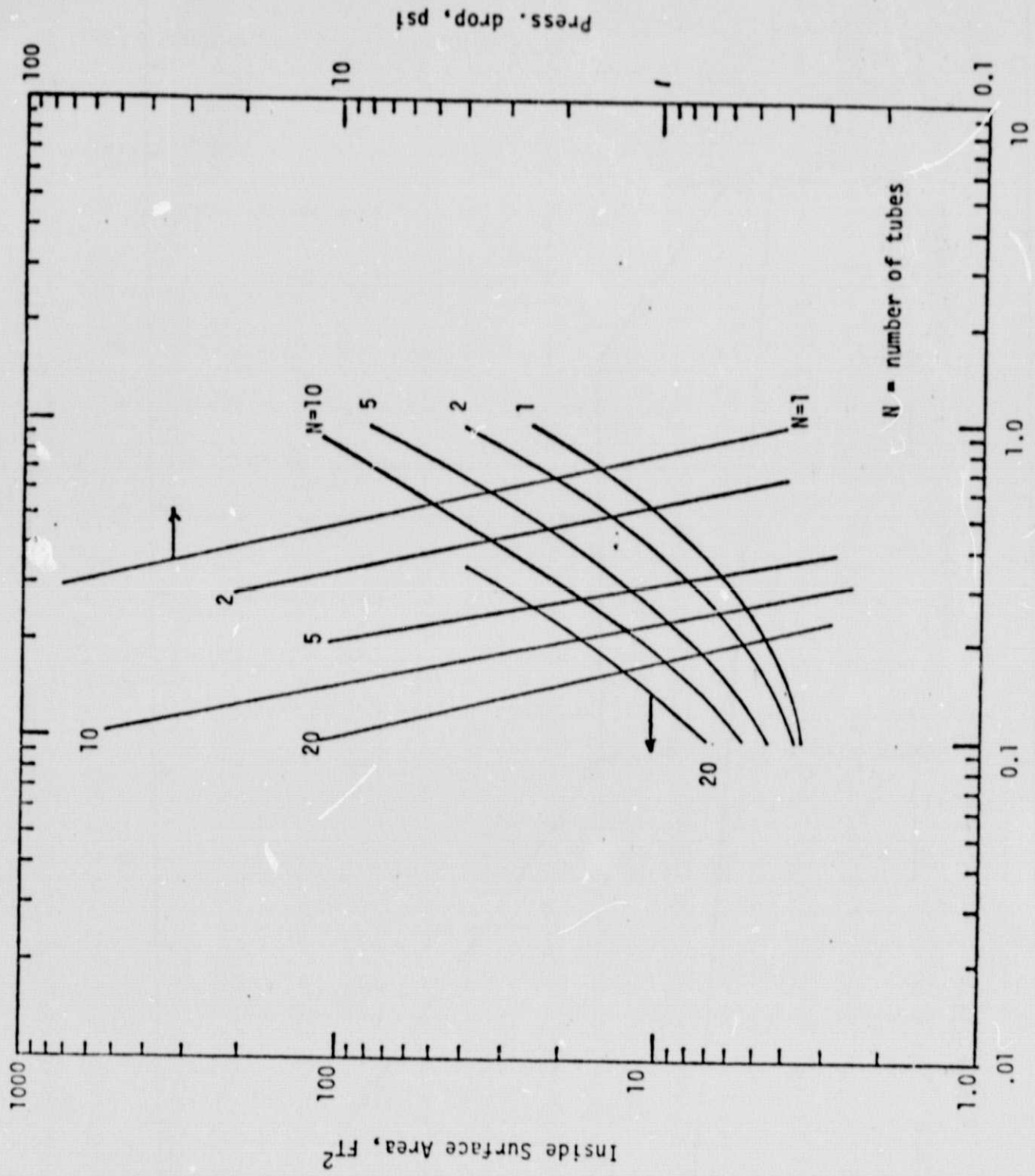


FIGURE 2-3 - Parametric Analysis Counterflow V.G.

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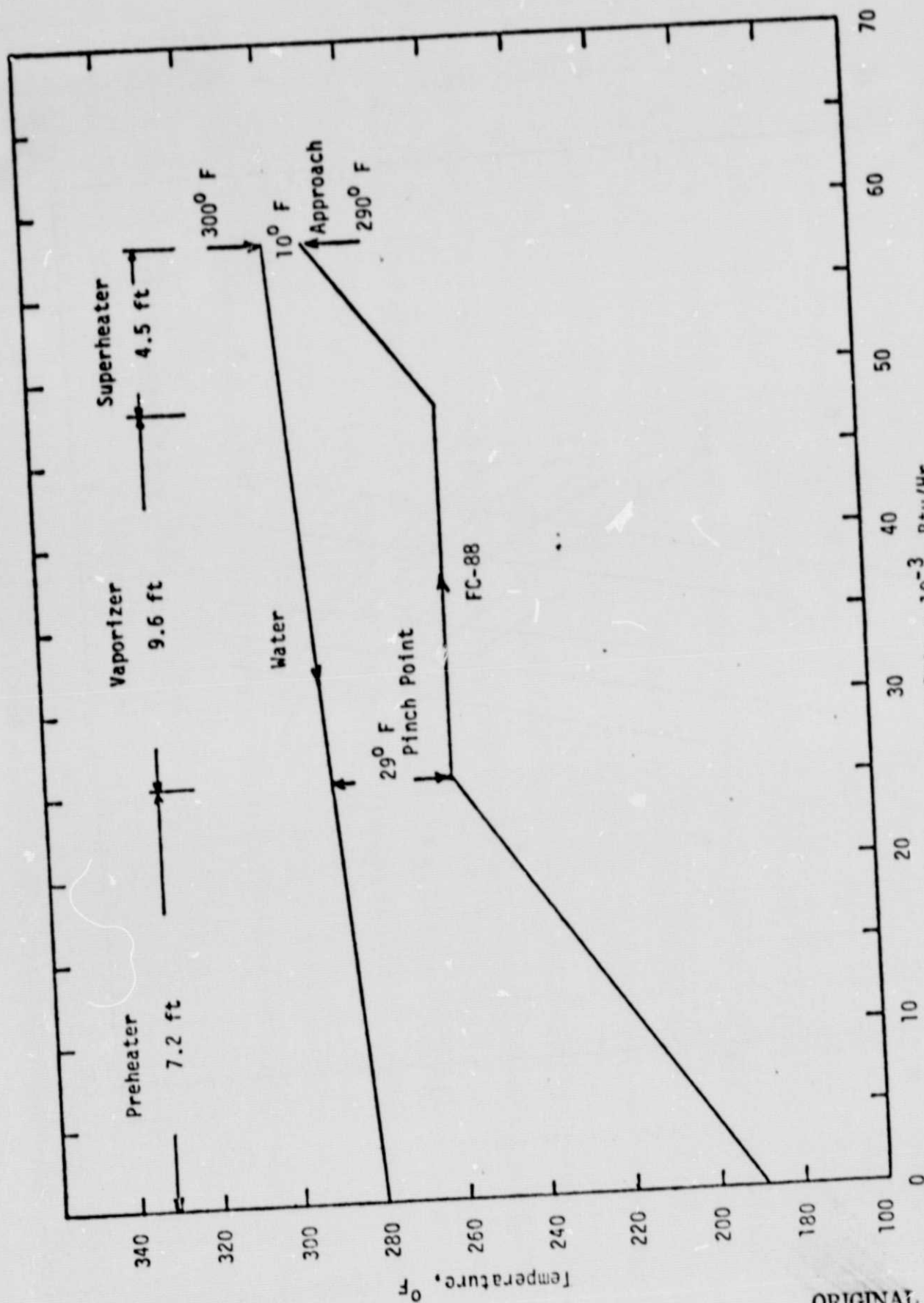


FIGURE 2-4 - Temperature Distribution for Vapor Generator

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The 10-ton vapor generator will be essentially the same as the 3-ton VG with the exception that it will contain up to 30 tubes in parallel.

The condenser coil for the outdoor unit incorporates the following heat exchange functions:

- Heat pump condenser (cooling mode)/evaporator (heating mode)
- Rankine condenser (cooling mode)
- Rankine feed pump motor cooler (cooling mode)
- Rankine feed pump sub-cooler (cooling mode)

The vendor selected for the 3-ton outdoor coil is the McQuay Group. The basic plate fin coil configuration and construction parameters have been completed. The selection of the Rankine/heat pump fluids circuitry to provide optimum use of the heat transfer surface is in process.

#### 2.5.4 Packaging

Both the 3-ton indoor and outdoor unit configurations have been selected and are shown in Figure 2-5 & 2-6 . The indoor unit cabinet, air flow system, and indoor coil assembly fabrication has been initiated. The solar hydronic coil design specifications were completed. The outdoor unit appearance design was completed and fabrication initiated. Initial assembly studies are in process. A representation of the 3-ton outer cabinet/frame assembly is presented in Figure 2-7. Air-flow system components have been selected and are on order.

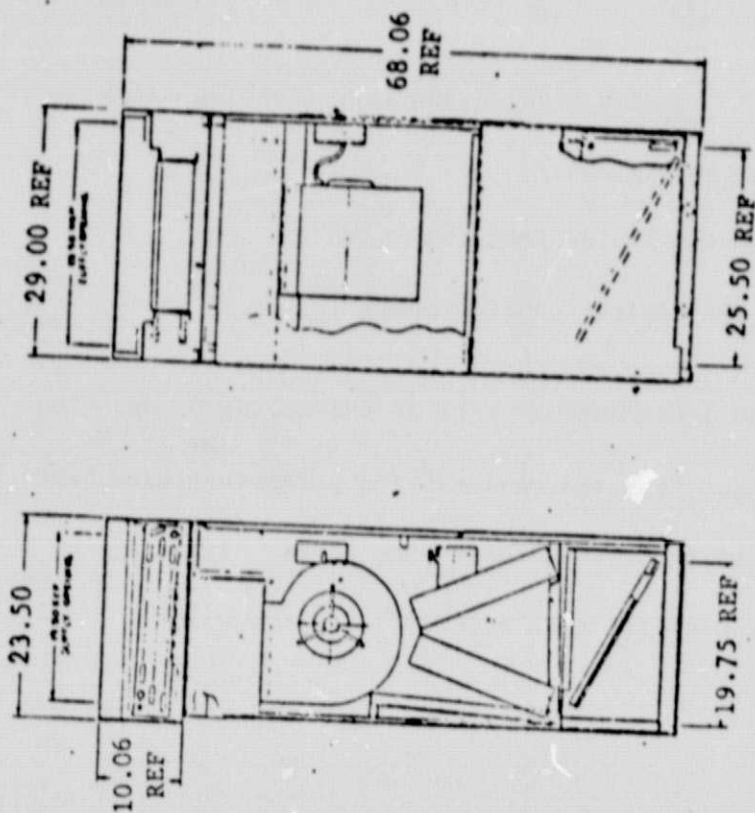


FIGURE 2-5 Indoor Section 3-Ton HRE Heat Pump

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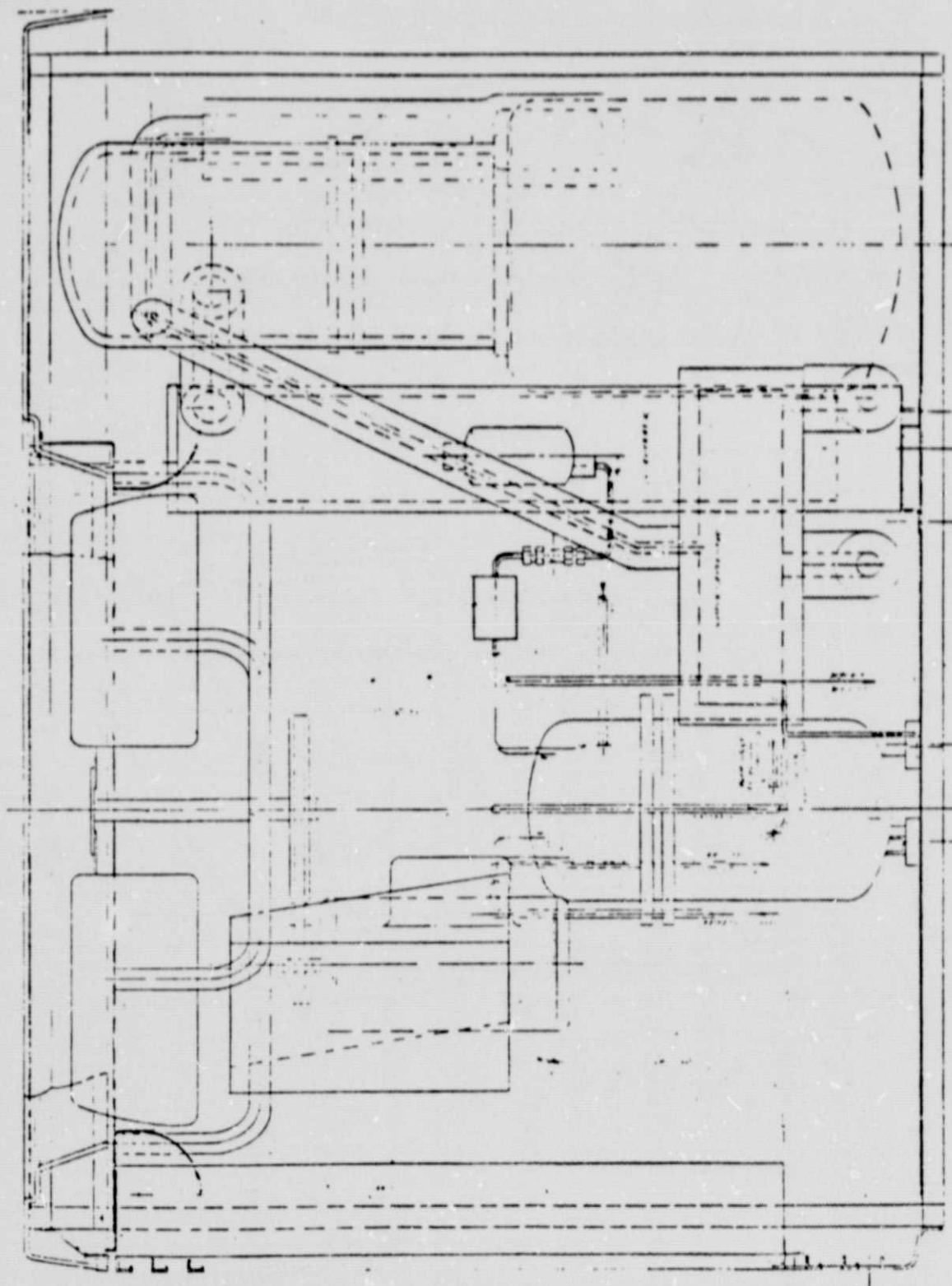


FIGURE 2-6 3-Ton Outdoor Elevation View

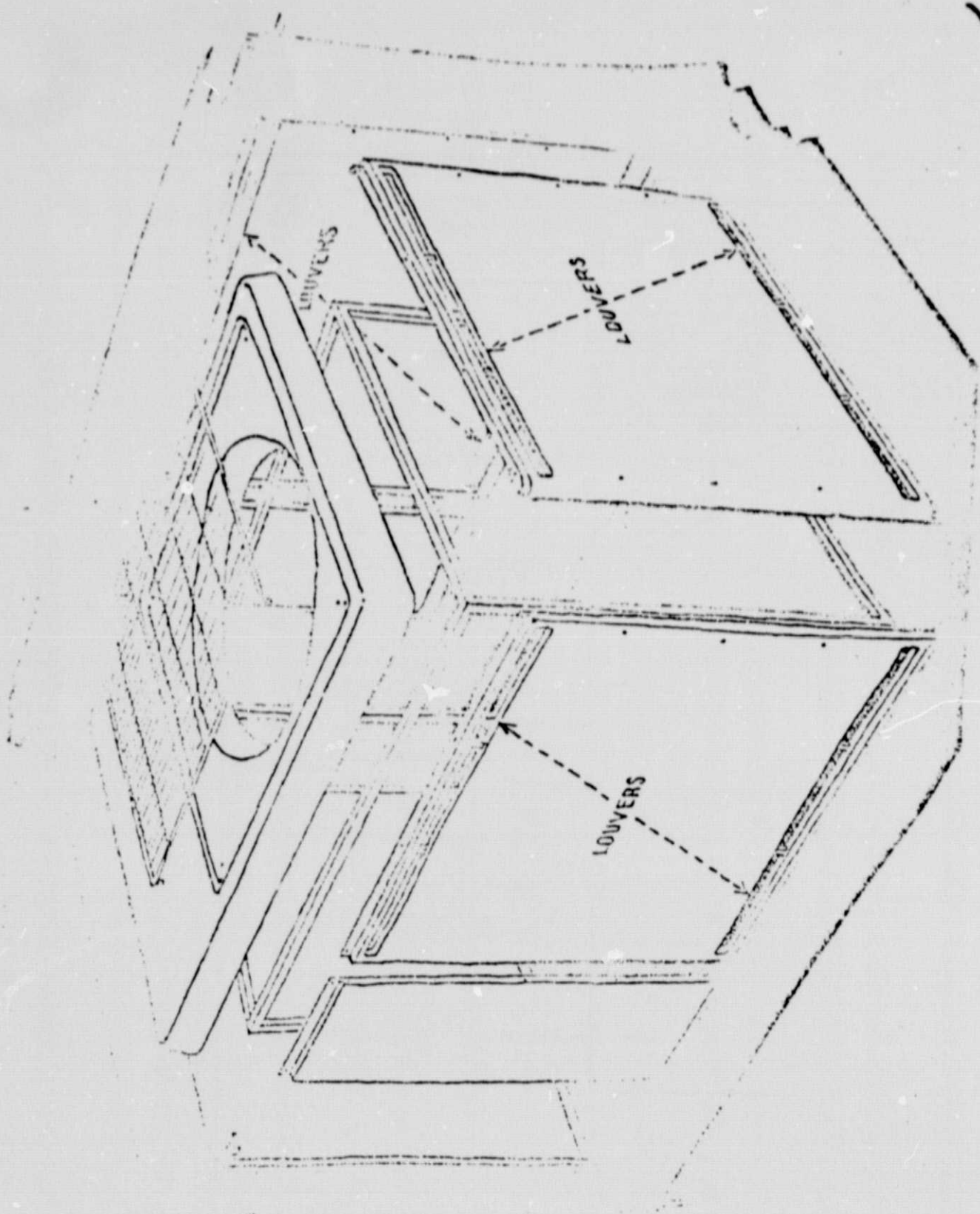


FIGURE 2-7 3-Ton Outer Cabinet/Frame Assembly

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## 2.6 Test

Testing proceeded at the component and subsystem level for the three ton heating and cooling configurations.

### 2.6.1 Low Temperature Rankine Component Test Loops

Extensive testing of the three ton expander was conducted during this reporting period utilizing the operational "A"-Loop test facility. One of the test facility features that proved most useful this period is the "Unattended Operation Mode" which provides automatic shutdown of an expander test in the event of a test facility or expander anomaly. Overnight and weekend continuous operation of the three ton expander was successfully accomplished without incident.

The planning is completed for the test facility changes required to accommodate the new two stage expander. Changes to the test loops include higher range temperature controls for the 150 KW simulated solar fluid source, higher range temperature and pressure sensors, modified loop components e.g., liquid separators, vapor generators, condensers and feed pumps. New mounting fixtures, and inlet and discharge piping interfaces will be designed and built for the three ton and ten ton expanders.



### 2.6.2 Magnetic Drive Testing

Figure 2-8 shows the schematic for the magnetic drive test stand currently under construction. The basic stand is the 10 ton size expander stand configured for horizontal testing. The hydraulic pump and hydraulic drive motor is on order, also the 0-200 in lb. torque motors. Completion of the test stand including checkout and calibration is scheduled for the latter part of May 1978.

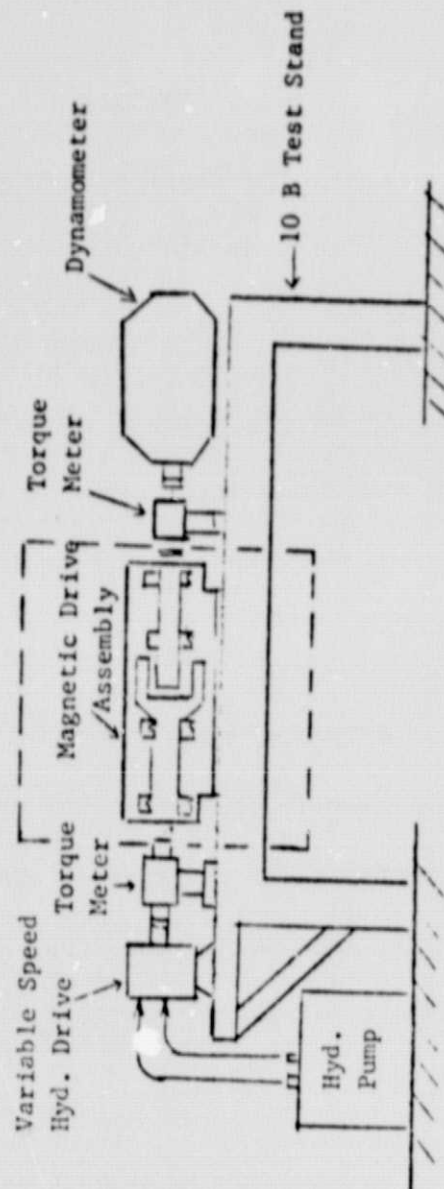


FIGURE 2-8 Magnetic Drive Test Stand

## SECTION 3

### Deliverable Hardware

#### 3.1 Normal

The deliverable hardware for Normal, Illinois, has been delivered and received on site less Solar Integrator. A Solar Integrator was made available for system start-up. The prime integrator will be delivered to the site mid-April.

#### 3.2 Spokane

The deliverable hardware for the Spokane site has been delivered and received on the site less shrouds, controls and heat dump alarm. The glass shrouds will be shipped in May 1978, controls to be shipped 4/6/78, and heat dump alarm by mid-April.

#### 3.3 Milwaukee

Milwaukee hardware is on hold pending site definition.

## SECTION 4

### Operational Test Sites

#### 4.1 Site Identification

The sites that have been investigated to date are listed in Table 4-1 and those that have been accepted are listed in Table 4-2. At the request of W. Hagan, NASA-MSFC, sites located in Valley Forge National Park were investigated as defined in Table 4-1. While one or two of those could be utilized it is GE's opinion that an alternate site would be preferable if available.

Investigation for a new HCOM-1 site are underway following the cancellation of the Martin Luther King Community Center site. Possible sites include:

1. The Community Center at Washington Park Lagoon, Milwaukee, Wisconsin.
2. State office building in Madison, Wisconsin.

#### 4.2 Site Installations

##### 4.2.1 HSF-2, Normal Illinois

The HSF-2 operational test site at Normal, Illinois has been installed. The fluids were added to the system on March 14, 1978 and the glass shrouds installed on March 15, 1978. After a period of leak checking and operation the system will be insulated and the instrumentation system activated.

Table 4-1 Sites Inspected by GE

| Bldg. Type | General City  | Site                                         |
|------------|---------------|----------------------------------------------|
| HSF        | Baltimore     | 7502 Young St., Ft. Meade, MD                |
| HCOM       | Muscle Shoals | TVA Office at Muscle Shoals, AL              |
| HMF        | Nashville     | Airman's Quarters, AEDC, Tullahoma, TN       |
| HSF        | Peoria        | Chanute Air Force Base                       |
| HSF        | Peoria        | MHA, Champaign, Illinois                     |
| HSF        | Peoria        | ISU House, Normal, Illinois                  |
| HMF        | Schenectady   | MHA, Schenectady, NY                         |
| HMF        | Schenectady   | VA Hospital Staff Housing, Albany, NY        |
| HMF        | Schenectady   | Ely Park Housing, Binghamton, NY             |
| HCMF       | Chicago       | Ft. Sheridan, ILL                            |
| HCMF       | Chicago       | Great Lakes Naval Training Center            |
| HCOM       | Madison       | Hill Farm State Office Bldg., Madison, WI    |
| HCOM       | Milwaukee     | Washington Park Senior Citizens Center       |
| HCOM       | Milwaukee     | Washington Park Community Center             |
| HCOM       | Milwaukee     | Dr. Martin Luther King Community Center      |
| HCOM       | Spokane       | YWCA                                         |
| HCOM       | Spokane       | East Washington State College                |
| HCOM       | Spokane       | Community College                            |
| HCCOM      | Los Angeles   | West L.A. Municipal Building                 |
| HCCOM      | Los Angeles   | Department of Water & Power #1               |
| HCCOM      | Los Angeles   | Department of Water & Power #2               |
| HCCOM      | Los Angeles   | Peck Park Recreation Building                |
| HCCOM      | Los Angeles   | Police Credit Union                          |
| HCSF       | Dallas        | President's Home, Univ. of Texas, Dallas     |
| HCSF       | Dallas        | President's Home, N. Texas State, Denton, TX |
| HCSF       | Dallas        | Grad Student Housing at SMU                  |
| HCSF       | Philadelphia  | Visitor's Center, Valley Forge National Park |
| HCSF       | Philadelphia  | Rental House, Valley Forge National Park     |
| HCSF       | Philadelphia  | Ampitheatre, Valley Forge National Park      |
| HCSF       | Philadelphia  | Storage Barn, Valley Forge National Park     |



TABLE 4-2 OPERATIONAL TEST SITE STATUS (2/28/78)

| Type    | Site No. | Location               | Date Accepted<br>by GE | Comments                                            |
|---------|----------|------------------------|------------------------|-----------------------------------------------------|
| HSF-1   | OTS 32   | Ft. Meade, Maryland    | Jan. 19, 1977          | On Hold                                             |
| HSF-2   |          | Normal, Illinois       | Feb. 7, 1977           |                                                     |
| IMF     |          | Tullahoma, Tennessee   | Feb. 7, 1977           | Multi-family units dropped from program             |
| HCOM    |          | Muscle Shoals, Alabama | Jan. 197, 1977         | Converted to Heating and Cooling Site<br>on 4/20/77 |
| HCOM-1  | OTS-36   | Milwaukee, Wisconsin   | May 23, 1977           | MLK Community Center site withdrawn by<br>owner     |
| HCOM-2  |          | Spokane, Washington    | July 1, 1977           |                                                     |
| HCSF-1  |          | Dallas, Texas          |                        | SMU House recommended by NASA on<br>August 15, 1977 |
| HCSF-1  |          | Philadelphia           |                        |                                                     |
| HCCOM-2 |          | Muscle Shoals, Alabama | April 20, 1977         |                                                     |
| HCCOM-2 |          | Open                   |                        |                                                     |

Note: Great Lakes, Illinois was accepted as a HCMF site on February 7, 1977. All multi-family sites have been dropped from the program.

#### 4.2.2 HCOM-2 Spokane

The HCOM-2 system installation at the Spokane YWCA is proceeding. The following progress has been made:

##### A. Collector Loop

The collectors are all in place on the supports. 80% of the collector header piping was laid out and brazed together, but was not installed on the collector. The main feed lines to the collector have been welded to the pipe anchors (Detail 6 sheet M-1). The heat dump has been fully piped up. The flash and expansion tanks have been returned to the site, but none have been installed.

##### B. Storage Loop

70% of the storage loop piping has been installed and is now on it's permanent supports. No piping has been done in the TES tank room. Flow meter W 200 has been installed.

##### C. Distribution Loop

###### 1. Swimming Pool Distribution Loop:

75% of the swimming pool distribution loop has been installed and is on it's permanent supports.

###### 2. Hydronic Coil Distribution Loop:

80% of the piping is installed and on it's permanent supports.

D. Swimming Pool System Loop

60% of the swimming pool system loop piping is now installed on hangers.

E. Domestic Hot Water

60% of the pipe hangers have been installed but no piping has been installed.